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Sound insulation performance in Danish multi-storey housing 1850-2009 and upgrade possibilities to meet current regulations

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ABSTRACT

Denmark has 1 million dwellings in multi-storey housing and 2.7 million dwellings in total. According to a social survey in 2010, about 35% of occupants in multi-storey housing are disturbed by neighbour noise, while for other housing types, it's less than 10%. Thus, there is a strong need to improve sound insulation in multi-storey housing. The paper quantifies dwellings built in different periods of 1850-2009 and summarizes key characteristics of building types and constructions as well as related sound insulation performance, some being far from fulfilling the limits in the latest Danish regulations. Sound insulation data from selected building types are presented, and improvement potential and feasibility based on benefits and drawbacks of different solutions are discussed. To include practical experience in development of solutions, several housing associations have been contacted, but even when carrying out major refurbishment work, focus is on energy issues, building maintenance and visual qualities, and sound insulation improvement almost never considered. Thus, it is clearly a challenge to change the mind-set of involved parties to apply a more holistic approach and include sound insulation improvement, when upgrading dwellings in other aspects, implying reduced risk of acoustic slum and increased quality of life for occupants.

Keywords: Sound insulation, Dwellings, Building constructions, Building regulations

1. INTRODUCTION

The most recent social survey [1] carried out in Denmark is from 2010 and indicated that 35% of occupants in multi-storey housing are disturbed or annoyed by neighbour noise. The consequence is a reduced quality of life and thus there are good reasons for further investigations of the neighbour noise issue and of possibilities for improvement of sound insulation. For other housing types, less than 10% of occupants report disturbance.

Sound insulation is a core quality of a dwelling – like structural stability and fire resistance. Common to those qualities are that they are "hidden", i.e. they are invisible and won't reveal the quality level, unless exposed to a load within the performance area in question, and it's not possible for most people to evaluate the score of those three qualities. Although sound insulation is typically not experienced during the first visit and inspection of a potentially new home, sound insulation is - in contrast to structural stability and fire resistance - a quality, occupants are often reminded about in everyday life after moving in – and benefitting or suffering from, dependent on the quality level and exposure.

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WHO has addressed the issue of noise and health implications, cf. [2]. Thus, sound insulation is not only a question of comfort. It's also a question about health and about avoiding conflicts between neighbours, cf. [3] and [4].

Based on information about the housing stock, including number of dwellings, year of construction, regulatory sound insulation requirements, typical construction types and related sound insulation performance, it's possible to focus on research and initiatives, where it's most needed. This paper provides such overview information as well as examples of sound insulation improvements in old housing and in newer housing in Denmark.

Exchange and discussions of solutions for improvement of sound insulation take place also in a European COST Action TU0901 [5] "Integrating and Harmonizing Sound Insulation Aspects in Sustainable Urban Housing Constructions", and a database with different solutions will be initiated.

2. HOUSING STOCK IN DENMARK

The number of dwellings in different housing types is shown in figure 1. In Denmark there are about 2.7 million dwellings in total, of these about 1 million in multi-storey housing – having far the highest percentage of people being disturbed by neighbour noise. In Figure 2 are found graphs for number of dwellings according to year of construction, dwelling types being the same as in Figure 1.

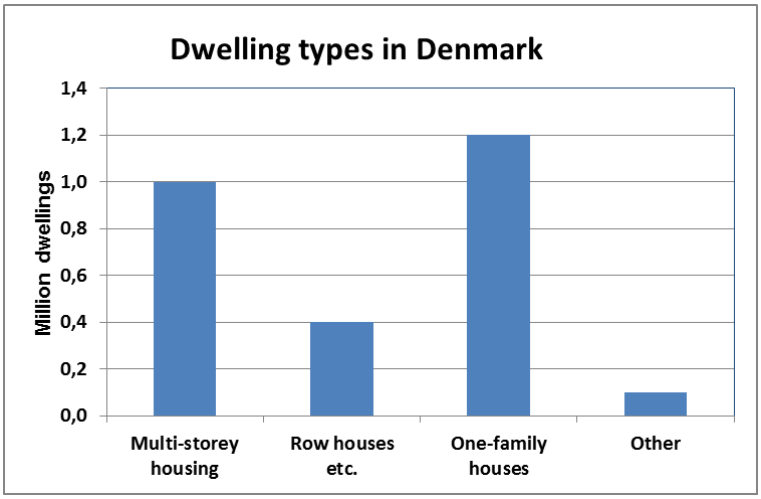


Figure 1 – Number of dwellings in Denmark 2012 according to dwelling type. Source: Statistics Denmark [6], rounded numbers.

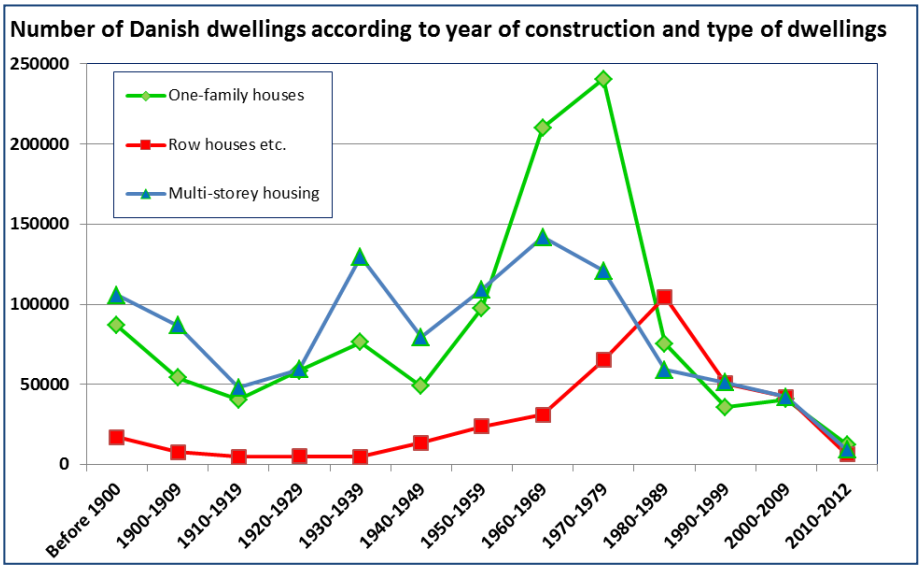


Figure 2 – Number of Danish dwellings according to year of construction and type of dwellings – 10 year periods from 1900-2009. Source: Statistics Denmark [6].

3. LEGISLATION

3.1 Building Regulations

Building acoustic requirements have been included in the Danish Building Regulations since 1956. A summary of the main requirements for sound insulation between dwellings as found in the successive Danish Building Regulations since 1956 is shown in Figure 3. Since 1982, R'_w and $L'_{n,w}$ have been used as descriptors for sound insulation in the Danish Building Regulations. Before 1982, various descriptors have been used in building regulations, but in Figure 3, the limit values have been converted to estimated values using the descriptors applied in the current regulations in Denmark.

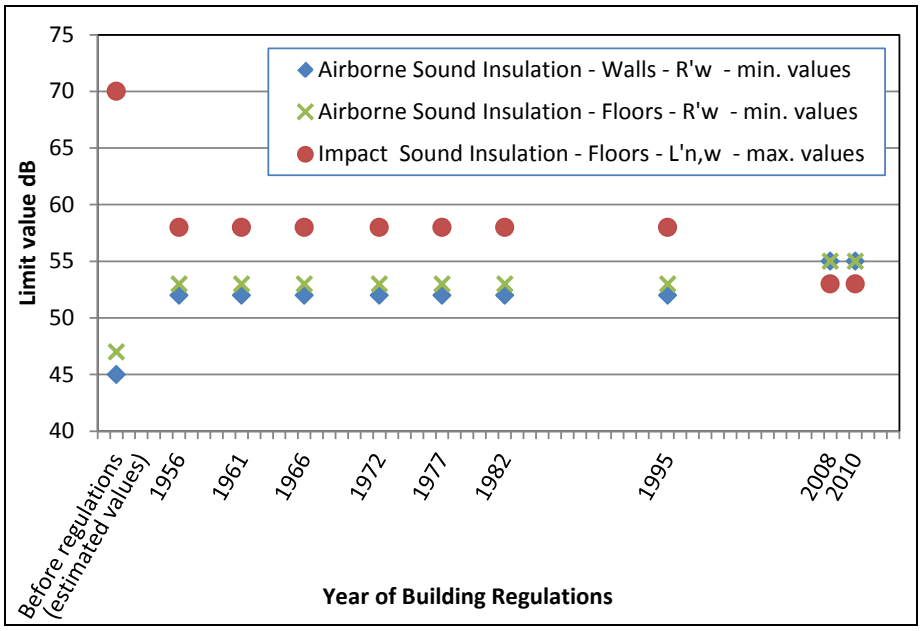


Figure 3 – Development in building acoustic requirements in the Danish Building Regulations. Refs: [7], [8]. Notes: The 1956 limits were for social housing only. All requirements have been indicated using estimated conversion to current descriptors.

It appears from Figure 3 that the limit values for airborne and impact sound insulation in Denmark have been constant for more than 50 years, until an adjustment was made in the Building Regulations from 2008. Before building acoustic requirements were introduced in Building Regulations, the quality of the Danish dwellings regarding sound insulation in general was lower. In Figure 3 are shown estimated values representing typical housing constructions from that period, i.e. thin brick walls and timber floor constructions.

3.2 Sound insulation of the past – today's reality

The major part of the housing stock in Denmark is built before 2010, the year where the stricter sound insulation requirements are estimated to be implemented in practice. Less than 1% of Danish dwellings have been built 2010-2012. According to experience, sound insulation in housing corresponds approximately to the regulatory requirements. Thus, 99% of the dwellings are expected to have sound insulation not fulfilling the requirements of today. Much refurbishment work has taken place during the latest decades, but unfortunately, sound insulation improvement is almost never addressed.

Unless refurbishment of the building stock includes an upgrade of the sound insulation, the quality of life for the majority of occupants in dwellings in multi-storey housing will be influenced from the poor sound insulation of the past. Approximately half of the existing dwellings in multi-storey housing are built before the first requirements were introduced, and the other half within the 50 years period preceding the tightening of the limits in 2008. Consequently, the sound insulation of the past is a reality of today for almost all people living in multi-storey housing in Denmark, and this will remain so, unless the challenge to change the mind-set to include sound insulation improvement in future refurbishment work is met.

4. BUILDING TYPES AND SOUND INSULATION PERFORMANCE

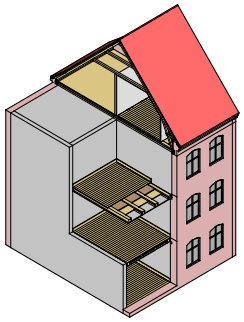
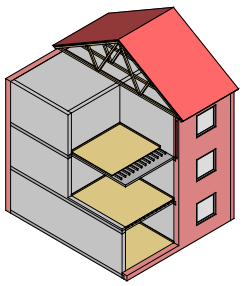
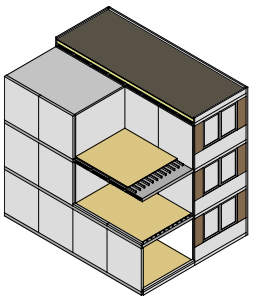
Main construction types for partitions between dwellings in multi-storey housing in Denmark are listed in Table 1 for different periods of time. The table also includes the approximate number of dwellings with the various construction types. Furthermore, estimated airborne and impact sound insulation values for the constructions are indicated.

Table 1 – Main construction types for partitions between dwellings in multi-storey housing in Denmark.

<table>
<tr><th>Period</th><th>Storey partitions
(2)</th><th>Walls between dwellings
(2)</th><th>No. of dwellings in multi-storey housing
(1)</th></tr>
<tr><td>Before 1900</td><td rowspan="4">Timber floors
R'_w 45 - 50 dB
$L'_{n,w}$ 63 - 75 dB</td><td>Timber frame brick walls (1/2-brick)
R'_w 42 - 45 dB
(3)</td><td>100.000</td></tr>
<tr><td>1900-1909</td><td rowspan="3">3/4-brickwalls
R'_w ca. 48 dB
(3)</td><td rowspan="2">200.000</td></tr>
<tr><td>1910-1919</td></tr>
<tr><td>1920-1929</td><td rowspan="2">200.000</td></tr>
<tr><td>1930-1939</td><td rowspan="2">Timber floors
R'_w 45 - 50 dB
$L'_{n,w}$ 63 - 75 dB</td></tr>
<tr><td>1940-1949</td><td>1/1-brickwalls, R'_w ca. 52 dB, or
in-situ concrete walls, R'_w 45 - 52 dB</td><td>100.000</td></tr>
<tr><td>1950-1959</td><td>Solid in-situ concrete slabs
R'_w 45 - 53 dB
$L'_{n,w}$ 58 - 65 dB</td><td>Concrete elements, R'_w 52 - 54 dB,
or 1/1-brickwalls, R'_w ca. 52 dB</td><td>150.000</td></tr>
<tr><td>1960-1969</td><td rowspan="4">Hollow core concrete slabs
R'_w ca. 53 dB
$L'_{n,w}$ ca. 58 dB</td><td rowspan="4">Concrete elements
R'_w 52 - 54 dB
(4)</td><td rowspan="4">250.000</td></tr>
<tr><td>1970-1979</td></tr>
<tr><td>1980-1989</td></tr>
<tr><td>1990-1999</td></tr>
<tr><td>2000-2009</td><td colspan="2"></td></tr>
<tr><td colspan="4">Sources:
Construction types: www.danskbyggeskik.dk [9], Engelmark, 1983 [10] and 2012 [11].
No. of dwellings: Statistics Denmark [6]
Sound insulation data: Based on SBi guidelines 172 [12] and 173 [13].</td></tr>
<tr><td colspan="4">Notes:
(1) The total number of dwellings in multi-storey housing in Denmark is approx. 1 million.
(2) In general there is a slight overlap of partition types between periods. In addition other construction types with lower sound insulation have been used in some cases.
(3) Until 1950, a minor part of dwelling partition walls were wooden partitions with thickness less than 10 cm and a sound insulation significantly lower than the indicated construction types.
(4) A minor part of dwelling partition walls have been light-weight double walls, especially in the last 1-2 decades in this period.</td></tr>
</table>

Based on the information in Table 1, it is found convenient to split up the housing stock into three main building types E1-E3, representing different typical construction types in different periods, see illustrations and brief descriptions in Table 2, and a new Danish guideline [14] for improvement of sound insulation between dwellings in existing housing is based on these three main building types (and in addition one type for row housing). Examples in this paper relate to building types E1 and E3.

Table 2 – Overview main building types and construction characteristics for multi-storey housing in Denmark. The building types are denoted E1-E3 as in a new Danish guideline under preparation [14].

Building type E1	**Building type E2**	**Building type E3**
Old brick-built buildings with timber floors Period: About 1850 to 1930/1950 Number of dwellings in Denmark: Approx. 500.000 dwellings.	Brick-built buildings with in-situ concrete slabs Period: About 1930 to 1960 Number of dwellings in Denmark: Up to 100.000 dwellings.	Concrete element buildings Period: From about 1960 Number of dwellings in Denmark: Approx. 400.000 dwellings.
		

Main construction types for building types E1 and E3 are found in Figure 4 and 5, respectively. The sound insulation performance values differ widely, cf. Table 1, as well as the needs and solutions for an upgrade corresponding to the new regulations ($R'_w \geq 55$ dB and $L'_{n,w} \leq 53$ dB).

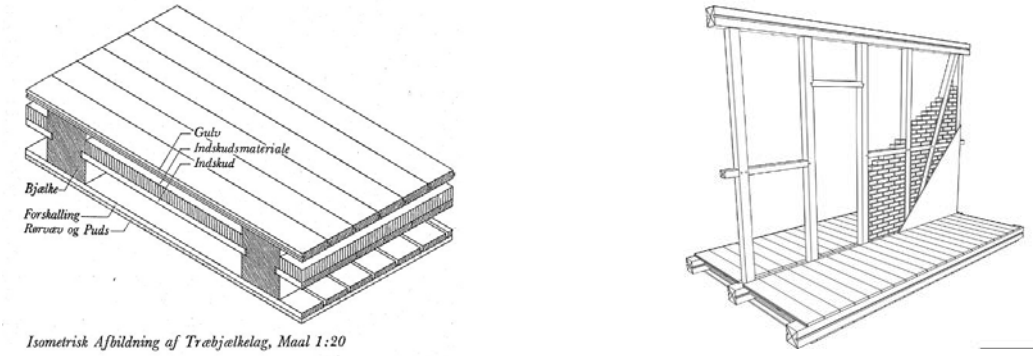


Figure 4 – Main construction types for building type E1.
Left: Typical timber floor construction with pugging (see also Fig. 6), approx. total thickness 280 mm, ref. [15].
Right: Typical timber frame brick wall (1/2 brick thickness) applied until 1900, ref. [11]. See also Table 1.

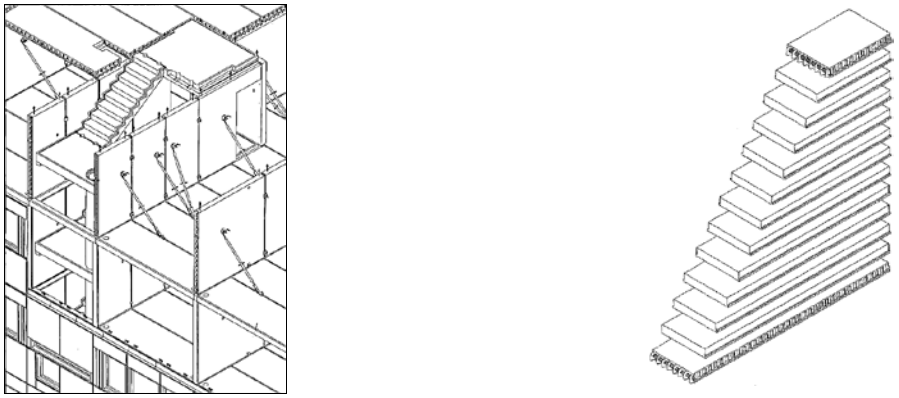


Figure 5 – Main construction types for building type E3. Left: Concrete element housing construction. Ref. Nissen, 1975 [16]. Typical wall thickness 150 mm. Right: Examples of prefabricated concrete elements in standard lengths 1780-5380mm, thicknesses 180 -275 mm. Ref. Nissen, 1984, [17].

5. EXAMPLES OF CONSTRUCTION IMPROVEMENTS AND TEST RESULTS

Two major projects [18] and [19] concerning improvements of the sound insulation between dwellings in the existing housing stock have been carried out in Denmark during the last years, and some examples and test results from field measurements of improved floor constructions are shown in Figure 6 and Figure 7. The focus for the examples is on impact sound insulation.

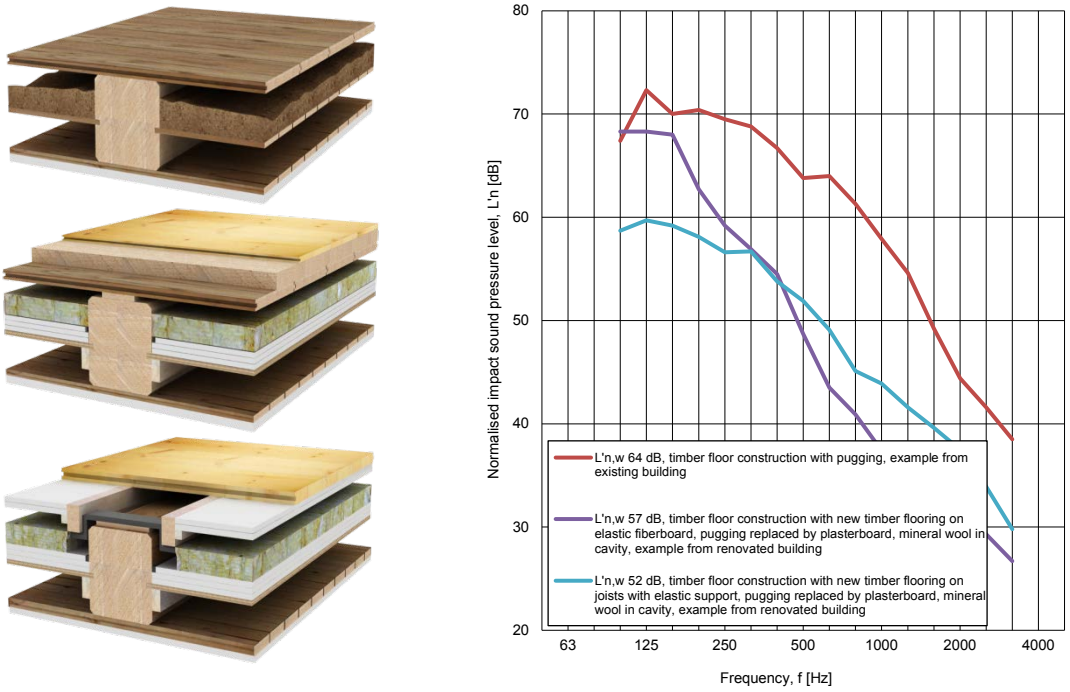


Figure 6 – Impact sound insulation, examples from measurements 2004-2005, ref. [20], in old housing with timber floors. Two different solutions for improvements are shown. Drawings are from [21].

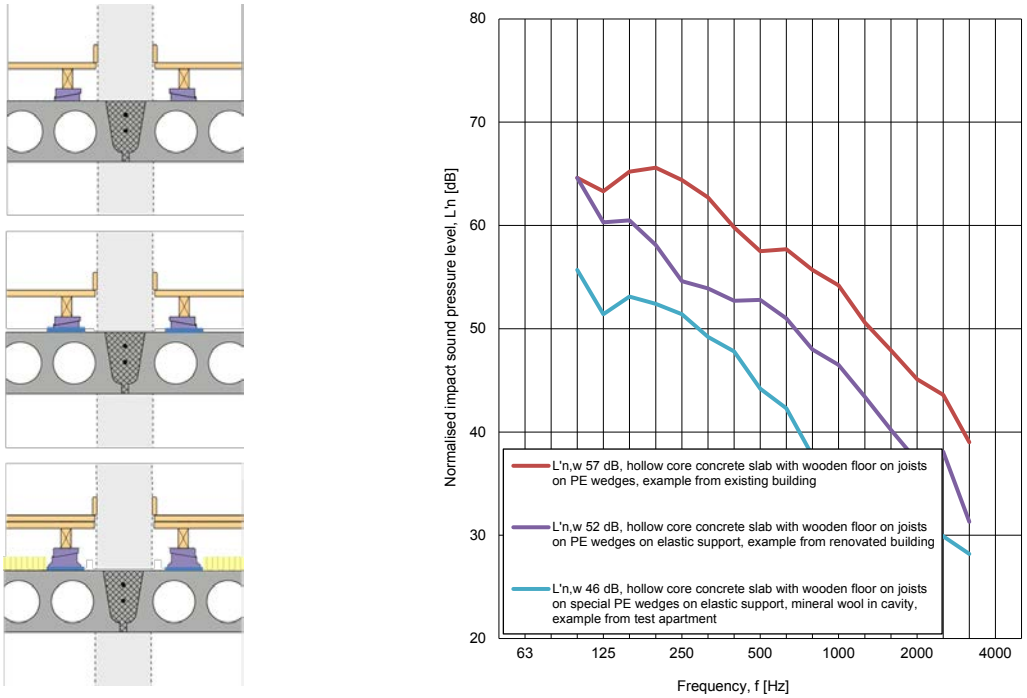


Figure 7 – Impact sound insulation, examples from measurements in 2012 in existing housing with hollow core concrete slabs. Two different solutions have been shown for improvements of wooden floor constructions, leading to compliance with new requirements (max 53 dB). Ref. [19].

The examples and results in Figure 6 are from the project "Better sound insulation in newly renovated homes" [18]. Different solutions for sound insulation improvement have been tested in the field during renovation of a block of flats from 1889. The typical Danish timber floor in this house had a weighted normalized impact sound pressure level $L'_{n,w}$ of 64 dB. A relatively simple solution by adding a thick elastic layer and a new wooden flooring reduced $L'_{n,w}$ to 57 dB, which is still 4 dB higher than the maximum limit 53 dB in the new regulations introduced in 2008. For other reasons than sound insulation, the pugging in this building was replaced by plasterboard. Fulfilment of the new requirements was solved using a more comprehensive solution consisting of a new wooden flooring on joists with elastic supports on iron mounting across beams, reducing $L'_{n,w}$ to 52 dB. Both solutions will increase the height of the floor, thus causing some adjustments of doors, doorsteps etc.

Figure 7 shows examples from multi-storey housing built from prefabricated concrete elements. The results are obtained from field measurements in a project [19]. The actual houses were built in the 1970's with 220 mm hollow concrete slabs with wooden flooring on joists on PE wedges. The weighted normalized impact sound pressure level $L'_{n,w}$ of the existing construction is 57 dB, thus fulfilling the requirements in the building regulations at that time. In contrast to many other countries in Europe, there is not a tradition of using heavy floating floors in Denmark, so the design of the lightweight floor construction on top of the concrete elements is decisive for the impact sound insulation performance.

During renovation of dwellings in two large building block areas the floorings had to be rebuilt. The example from the first area shows a rather simple solution by adding a thin elastic layer under the wedges. The height of the floor is barely influenced and the $L'_{n,w}$ is lowered to 52 dB, i.e. fulfilling the newest requirements. The example from the second area shows a more comprehensive construction with wooden flooring on chipboard on joists on special PE wedges on elastic support. This solution is till now only built in a test apartment in the building, but the $L'_{n,w}$ is reduced to 46 dB, thus significantly below the max level 53 dB requested by the new regulations.

6. HOLISTIC APPROACH WHEN UPGRADING HOMES FOR THE FUTURE?

Social surveys in Denmark in 2010 show that about 35% of people living in multi-storey housing are disturbed or annoyed by neighbour noise. In 2008, stricter sound insulation requirements for such housing were implemented in the Danish building regulations. However, building regulations are primarily intended for new housing, and status for 2013 is that about 99% of all flats in Denmark have been built before this tightening of requirements. About half of these flats were built in the preceding 50 years period with sound insulation requirements less strict than today, the other half from before approx. 1950 with no sound insulation requirements and with construction types having sound insulation performance far below constructions applied today. Also for other aspects than sound insulation, a big part of the dwellings in multi-storey housing are below or even far below today's standard.

During the latest decades, numerous refurbishment and renovation projects have taken place, most of these focusing on upgrading technical installations, kitchen and bath rooms and not least at energy savings. Unfortunately, sound insulation improvement is almost never addressed, not even in cases where sound insulation is known to be a problem.

Many organizations in Denmark have published books or other publications titled e.g. "Upgrading housing for the future", but again sound insulation is normally not addressed, although sound insulation is a core quality of the building and closely related to quality of life for the occupants.

Consequently, there is a strong need for a more holistic approach, when renovating housing, implying sound insulation upgrade to be considered and planned simultaneously with other upgrades of housing, especially with thermal insulation upgrades, where solutions sometimes reduce the sound insulation performance.

National initiatives related to upgrading sound insulation in existing housing could include sound insulation requirements to be enforced, when renovating housing – in exactly the same way as is the case for the quite strict thermal insulation requirements, which have been enforced in Denmark since 2008, also for changes in existing housing.

Several sound insulation improvement solutions exist, but more innovation, development and experience could contribute to a more smooth planning process and to optimization of solutions. However, it all starts with changing the mind-set of the involved parties, implying integration of sound insulation improvement to be considered obvious in line with other qualities.

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